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THE CONTROL OF SPACECRAFT CONTAMINATION - WHERE ARE WE GOING?

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Spacecraft contamination control was derived from technolgies developed for aircraft and missile systems. Fluid systems had to be free from particulates that could damage components, liquid and gaseous oxygen systems had to be free of materials that could react with the fluid, and for good housekeeping, a "visually clean" level of environment was maintained.

It soon became apparent that there were additional types of contamination problems. Spacecraft windows became clouded, thermal control surfaces were degrading at higher than anticipated rates, and particulates around spacecraft were affecting star sensors.

The symposium on optical contamination in space, sponsored by the Rocky Mountain Section of the Optical Society of America, was held in August 1969. A review of the program shows that most of the topics from that symposium are still of interest.

This paper will note the current problem areas and discuss the subject from a system engineering point of view. Among the topics to be discussed are project organization for contamination control, standards, cost, and major unresolved issues.

THE FOLLOWING ABSTRACTS HAVE BEEN RECEIVED FOR THE CONFERENCE.

SESSION AND PAPER NUMBER ARE BEFORE EACH ABSTRACT.

A COMPILATION OF COMPLETE PAPERS WILL BE PUBLISHED AS A TECHNICAL REPORT AND WILL BE SENT TO ALL CONFERENCE ATTENDEES.

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OUTGASSING OF MATERIALS IN THE SPACE ENVIRONMENT

A THERMOKINETIC APPROACH

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ABSTRACT

Previous efforts to model the outgassing of polymers on spacecraft have been partly empirical and partly educated guesses. None of these approaches have been successful in effectively describing the process in terms of time and temperature in such a manner that outgassing could be predicted in advance so that valid assessments could be made of its effects on various optical systems.

This report provides a fresh approach to this problem by relating the outgassing to basic chemical reaction kinetics, which provides a powerful tool for such estimations and also provides an insight to the basic mechanisms involved. The general equations of the total outgassing quantity are derived, as well as the outgassing rates, as functions of time and temperature. The results are shown to be consistent with experimental data obtained in earlier programs. While there is much evidence that suggests outgassing is primarily a first-order reaction, the equations are presented here for both first-order and other-than-first-order reactions.

The power of the reaction-kinetics approach lies in its applicability whether the outgassing mechanism is due to desorption, diffusion, thermal decomposition or evaporation. It also illuminates those situations where only minor constituents of the parent material outgas, or whether the entire substance may outgas.

To implement the use of this approach certain thermokinetic parameters must be measured for each material of interest. It is suggested that the necessary data can be obtained through sensitive thermogravimetric analysis (TGA) techniques.

Abstract

An analytical model to compute the net deposition rate of volatile condensible materials (VCM) on the surfaces of a satellite in deep space is derived from the Boltzmann equation of molecular transport.

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An analytical model is derived to calculate the deposition of volatile condensible materials (VCM) which are released from various non-metallic source materials on a satellite in the space environment. The derivation defines an appropriate molecular velocity distribution and results in an integro-differential Boltzmann equation of transport in spherical coordinates for the transport of VCM molecules through an absorbing and scattering medium. In deep space the assumption of collision-free transport results in free molecule flow with a Maxwellian distribution in speed. Subsequently the velocity vector distribution can be formulated as the product of a scalar speed distribution and a spatial distribution of molecules which is equivalent to the one-group approximation of the transport equation which is applied in neutron analysis.

Under free-molecule conditions, the usual spatial integration of the Boltzmann equation is transformed into a surface integration over the N nodes of an enclosure which bound the VCM vapor where each nodal surface has a different temperature. This divides the net mass flux vector into N^2 components which are coupled to the source mass emission rates by an $N^2 \times N^2$ flux coupling matrix. The elements of this matrix are algebraic functions of the diffuse angle factors between the nodes and a set of N^2 empirical condensation coefficients. Finally, a mass continuity balance results in a set of N linearly coupled equations which simultaneously compute the net mass deposition rate on each node.

To apply the equations, the time-dependent outgassing characteristics of the source nodes and reemission from VCM nodes as well as the condensation coefficients must be experimentally determined for the temperature range through which the system is to operate. If gravimetric techniques such as vacuum microbalances and quartz crystal microbalances (QCMs) are used to measure the source and VCM kinetic properties, then the equations derived will compute the nodal mass flux transport without explicit knowledge of any VCM molecular properties. However, if the molecular weight can be determined, then the nodal vapor pressure and heating rates can be computed from the local momentum flux tensor and the energy flux vectors respectively.

OUTGASSING RATE DATA FOR MULTILAYER INSULATION MATERIALS

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Outgassing rate data have been obtained for multilayer insulation (MLI) materials. The materials tested include double aluminized Mylar, Dacron net and various other shield and spacer material. The data are in the form of mass evolved per unit area per unit time for isothermal specimens as a function of time for a range of constant temperatures. Data of this type are needed to resolve at least two common practical problems. First, MLI is a significant source of water vapor, which can condense on critical surfaces of cooled sensor systems. There is evidence that water vapor condensation has caused failure or serious degradation of several orbiting sensors which incorporate a considerable quantity of MLI in their design. Second, it is generally found that the effective thermal conductivity of MLI wrapped on a practical system is significantly higher than the ideal value determined by flat plate calorimetry. The higher practical conductivity would be caused by the presence of outgas products, which could cause additional gas phase conduction, or could condense on shield surfaces increasing their emittance. Though this may not be the reason, outgassing data are necessary for diagnosis.

MLI outgassing rate data have been generated previously, but the apparatus and techniques used were generally of less than adequate accuracy, sensitivity and flexibility to generate the type of data needed for solving engineering problems of the type noted. The experimental techniques used in these earlier determinations were based on pressure measurement, and were subject to errors in absolute magnitude and low sensitivity. The present data were obtained using a recently developed apparatus of high accuracy and sensitivity which uses a liquid nitrogen temperature quartz crystal microbalance to collect outgas efflux from a Knudsen cell-type sample holder. In this paper the new data are compared with the earlier data for equivalent test conditions.

Possible theoretical models for the outgassing process are presented and discussed. The time dependence of the outgassing rate is neither inverse half power or, as would be expected from simple bulk diffusion or simple surface desorption mechanisms. This indicates that a more sophisticated outgas model is required, so, following the suggestion of previous workers, a model based on a distribution of activation energies has been investigated.

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APPLICABILITY OF THERMOGRAVIMETRIC ANALYSIS TO SPACE CONTAMINATION

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To establish the extent of the induced contaminant environment and its effect upon a satellite, analytical approaches have been developed to define and quantify the principle parameters. This has been accomplished through developing equations which contain all the proper physical relationships which are then supported by necessary testing. To characterize the contaminant source, material properties such as the molecular mass loss rate per unit area of the surface as a function of temperature and time are needed. The bulk of the material data available is testing based on TML/VCM at a source temperature of 125°C and a collector temperature of 25°C. Extrapolation of TML/VCM to other temperatures is questionable, especially to the high temperatures expected after a laser impact. The technique of thermogravimetric analysis (TGA) is being studied as a candidate material test procedure tó provide the necessary material parameters for contaminant source equations. Extensive TGA tests have been performed to characterize some of the factors that influence the thermogram of the sample. Both dynamic and isothermal TGA will be reviewed to determine their advantages and problem areas.

OUTGASSING MEASUREMENTS ON MATERIALS IN VACUUM USING A VACUUM BALANCE AND QUARTZ CRYSTAL BALANCES

by

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For the prediction of cleanliness levels around spacecraft and on critical spacecraft surfaces one needs besides a mathematical model a number of outgassing characteristics on spacecraft materials.

What is required is the time and temperature dependant data such as the total outgassing rates, condensation rates of the contaminants produced onto, surfaces and re-evaporation rates.

As the Micro-VCM outgassing data are of limited value in the prediction of spacecraft contamination ESTEC developed an outgassing system using a vacuum balance and quartz crystal balances.

The idea behind this development is the desire to obtain Arrhenius type outgassing equations in which the outgassing is a function of temperature, activation energy and time.

This paper describes the outgassing system and gives a number of test results.

SHUTTLE ORBITER/SPACELAB INDUCED ENVIRONMENT TECHNICAL OVERVIEW

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ABSTRACT

This paper presents a compilation of the results of a systems level contamination analysis and related computer modeling activities conducted by Martin Marietta Aerospace, Denver Division over the past three years under in-house Internal Research and Development activities and separate contracts to Johnson Space Center for the Shuttle Orbiter and Marshall Space Flight Center for the Spacelab carrier. It depicts our current technical assessment of the contamination problems anticipated during the STS program and presents recommendations for contamination abatement designs and operational procedures based upon experience gained in the field of contamination analysis and assessment dating back to the pre-Skylab era.

The impact of the induced contaminant environment of a space vehicle has recently become extremely important as a basic design parameter for such sophisticated programs as the NASA/DOD Space Transportation System (STS) and its numerous ultrasensitive payloads. The degree of efficiency to which the STS design meets the contamination control criteria as dictated by the STS payload community will determine the ultimate utility of the STS to provide the scientific and military communities with the platform from which to conduct desired investigations with assurance that the induced environment will not compromise payload objectives.

To accomplish this, the scientific user community has established certain contamination control criteria for the STS to attempt to motivate the spacecraft designers to consider the contamination impacts in their final product. These criteria are discussed along with their meaning as translated to the ultimate STS design through use of a contamination computer model.

Included in the criteria are limitations on: 1) the total number of contaminant molecules along a scientific instrument line-of-sight; 2) the number of particles appearing within a scientific instrument's field-of-view; 3) the background brightness induced by scattering or emission of radiant energy by the contaminant environment; 4) the return flux of contaminant molecules to a sensitive surface resulting from collisions with the ambient atmosphere; and 5) the level of contaminant deposition and/or the resulting absorption of radiant energy on a sensitive surface.

As a result of the systematic evaluation of the STS induced contaminant environment, conclusions are drawn and recommendations for STS/payload design and operational contamination avoidance are made. The primary conclusion developed from this evaluation is that due to the programmatic requirement that the STS be a highly flexible/diversified vehicle with a multitude of uses and objectives that a contaminant free environment acceptable to all payloads cannot be provided economically through design alone. The proper approach would, therefore, be to optimize the current design and institute strict mission timeline and operational planning based upon individual payload mixes and mission objectives. Such planning will dictate allowable orbital altitudes, attitudes, vent timelines and exposure times for a particular mission to minimize potential contaminant impacts.

INFRARED RADIATION FROM THE SPACE SHUTTLE CONTAMINANT ENVIRONMENT by J.P. Simpson and F.C. Witteborn, Space Science Division, NASA-Ames Research Center, Moffett Field, CA 94035.

The Space Shuttle contaminant environment consists of molecules and particles originating on the Shuttle. The molecules come from outgassing, cabin leakage, flash evaporators and other man controlled vents, and rocket exhaust. Particles are thought to come from abrasion, ablation of surfaces, dust trapped in cracks, dust from vents and cabin leaks, ice particles from improper venting, and droplets of unburned fuel. Simpson and Witteborn (1977, Applied Optics 16, 2051-2073) have discussed the effect of the infrared radiation from molecules and particles from 4 μm to 200 μm on a sensitive infrared telescope. (This paper also discusses non-Shuttle infrared sources such as the atmosphere of the earth and the interplanetary dust/zodiacal light.) They conclude that the radiation from the contaminant environment is tolerable only when it is at its minimum--when there are no rocket firings and the flash evaporators and the manually controlled vents are not being used. This report extends the predicted infrared spectrum from the molecular contaminants H_2O and CO_2 down to 2 μm. It also discusses the sighting frequency and infrared spectrum of particles caused by spallation of the surfaces of the Shuttle tiles by micrometeoroid impact.

H_2O and CO_2 are the most important infrared active molecules that come from outgassing, cabin leakage, or evaporators. It is assumed that the initial populations of the molecular levels are given by thermodynamic equilibrium (TE). In a vacuum the molecules radiate until they come into equilibrium with the radiation field of the earth and sun. The time it takes depends on the Einstein transition probability. Meanwhile the molecules move away from the Shuttle; only the nearby ones are detected by Shuttle-borne experiments. Consequently the radiation from transitions with small transition probabilities (long lifetimes) is given by the TE formulae (such as the 15 μm band of CO_2 and the 6.3 μm band of H_2O). Bands with large transition probabilities (such as the 4.3 μm band of CO_2 and the 2.7 μm band of H_2O are in equilibrium with the radiation field of the sun or earth (the latter is very weak). Since the Shuttle is actually moving through the earth's upper atmosphere, the H_2O bands are also excited by collisions with oxygen atoms. This results in additional radiation. For CO_2 this excitation is almost negligible.

The surface of the Shuttle tiles is coated with borosilicate glass. Hypervelocity impacts of micrometeoroids make small craters, from which particles are ejected at high velocities (other particles are ejected at low velocities). The shocked or even melted particles have much higher temperatures than the surface; they cool to ambient within a few seconds. However, because of the high velocities, most of the particles that pass through the 15' field of view of a one meter diameter telescope do so almost immediately after ejection. The spectrum of the 1-20 μm particles is that of a silicate, with emission peaks at 10 μm and 20 μm and emissivities that decrease rapidly at longer wavelengths.

Estimates of radiation from the sources discussed here do not change the authors' earlier conclusion that the Shuttle environment would be suitable for sensitive infrared astronomical observations with appropriate constraints on Shuttle observations. The nature of the expected sources, however, should be considered in the design of instruments planned for use in the Shuttle environment.

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Spacecraft Contamination Model Development

By

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This paper presents the results of the computer modelling activities and related systems level contamination analysis conducted by Aerojet ElectroSystems Company. A contamination model is defined that has application to any spacecraft system. The model originated during on-going programs conducted for the Air Force. The model has three major elements that can be integrated into concise sets of equations. The basic elements are source kinetics including deposited material desorption kinetics, transport mechanisms and degradation effects.

The Aerojet Mass Analyzer Program (AMAP) is designed to determine the contaminant source emission and re-emission mass deposition rates on the surfaces of a vehicle in a space environment using line of sight theory and diffuse emission behavior. This program also accounts for the deviation from these assumptions for surfaces such as thrusters with special shape factor input parameters. The program is capable of analyzing the contaminant mass distribution and subsequent degradation effects for problems with up to 130 nodes and 40 different source and deposited contaminants. Such a solution is found by computing a separate solution for each contaminant and superimposing these solutions for the complete solution. Sticking coefficients are in reality accommodation coefficients as used in this program. Multiple reflections are accounted for in the solution. This allows for complex geometries to be considered as a function of temperature. It is assumed that the small quantity of mass (percentage-wise) which is elastically reflected and is not accommodated on any surface is lost to space. The model is being further developed to determine the return of ionized spacecraft generated molecular material and subsequent interaction with the magnetosphere (space charge effects).

The correlation of the analysis with observed radiator degradation of a geosynchronous altitude satellite will be briefly presented to show the merit of the modelling approach.

An Improved Analytic Technique to Predict Space System Contamination

By

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Ability to predict contamination deposits on sensitive surfaces of a space system due to mass transport effects is desired for environments ranging from atmospheric pressure to the hard vacuum of deep space. Line-of-sight contamination model theory ignores molecular collisions and therefore may yield considerable prediction error when applied to high molecular density situations. This problem has been addressed by defining an index parameter which dynamically evaluates the local molecular collision frequency and indicates whether a line-of-sight transport model is valid or if a model which accounts for molecular collisions should be used. For an index parameter value of less than 10^{-3} collisions/sec/cm^3, the line-of-sight model can be accurately applied. However, for the early phases of typical space missions (generally including prelaunch activities through insertion) the collisional frequency ranges up to thirteen orders of magnitude higher than the threshold value. Therefore a diffusion transport mechanism prevails which can cause significant intra-surface mass flow not accounted for by line-of-sight theory. The number of molecular interactions can easily exceed 10^{16} collisions per cubic meter of payload volume during a pre-insertion period of 10^3 seconds.

A new mathematical model to predict diffusion mass transport among surfaces is described which accounts for inter-molecular collisional behavior. The mathematical characterization utilizes dynamic thermal history behavior for the surfaces of interest. It evaluates the instantaneous local atmospheric pressure prior to and during ascent to calculate molecular collision probabilities. Adsorption coefficients for various temperatures are evaluated for each surface in a manner which simulates their mission temperature cycles. The input data for this portion of the contamination model is developed from thermal models, and a "sojourn" time and accommodation coefficient description is applied to surface behavior.

The model has been used to predict net contamination conditions at insertion for a geosynchronous satellite launched on a Titan 34D vehicle. Output data from that analysis is presented and further applications to alternative launch techniques are reviewed. A description of the parametric index which allows selection of either the diffusion or the line-of-sight contamination transport calculations, as appropriate to the mission instantaneous environment, is also given.

SHUTTLE FLOW FIELD ANALYSIS USING THE DIRECT SIMULATION MONTE CARLO TECHNIQUE

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A direct simulation Monte Carlo program has been developed which is capable of analyzing the nonequilibrium, three-dimensional external flow in the vicinity of the orbiting Shuttle. The volume of the flow field surrounding the Shuttle, within which the analysis is executed, is typically of the order of $10^6 m^3$. The external flux density incident on the flow field boundaries is calculated from the properties of a Maxwellian gas drifting at orbital velocity. The internal flow field boundaries are the Shuttle surfaces, the geometry of which are written into the program code. The program provides for surface emission (outgassing) and discrete Shuttle gas sources located at prescribed points on the Shuttle (leaks, dumps, rockets). The program honors all the physical conservation laws, molecular collisions are calculated according to classical collision dynamics using either hard sphere or inverse 9th power molecules, throughout the flow field all modeled molecule trajectories are calculated incrementally, and molecular emissions and reflections from the Shuttle surfaces are treated according to the cosine law. Problem variables which are specified by numerical input include: orbital velocity, freestream density and temperature, collision cross section, Shuttle angle of attack, surface temperature, bay doors open or closed, surface outgassing rate, and Shuttle discrete source fluxes. The flow field variables computed in the Monte Carlo analysis include: the density, velocity and temperature distributions throughout the flow field, the backscattered flux density (upstream flow), the flux density incident on each element of the Shuttle surface and the molecular column density as viewed from the payload bay in specified directions. In addition to these parameters, the calculations yield separately the density, flux density and column density distributions for freestream molecules, surface reflected molecules, collisionally affected molecules, outgassing molecules, and discrete source molecules. Both transient and steady-state flow phenomena may be analyzed.

Flow field analyses have been made for a range of orbit heights, Shuttle outgassing rates and Shuttle attitudes. It is found that for Shuttle outgassing rates approaching the maximum expected value, the return flux density of outgassed molecules incident on some of the Shuttle surface elements is comparable with the stationary freestream flux density. This result implies that some experiments conducted in the payload bay (such as astronomy experiments which use low temperature optics) may risk contamination. It is further found that the backscattered flux density (upstream flow component) can exceed the stationary freestream flux density and that this component disappears only well aft of the Shuttle. This result is important in determining the location of the molecular shield since this flux density can enter the molecular shield and contribute to the shield internal density and contaminate the experiments conducted within the shield. Computed flow field analyses will be presented and discussed with respect to contamination implications for experiments located in the payload bay, located in the immediate vicinity of the Shuttle, and located in devices which are separated from the Shuttle by a long boom (such as the molecular shield and the molecular beam apparatus).

NASA CHARGING ANALYZER PROGRAM - A COMPUTER TOOL THAT CAN EVALUATE ELECTROSTATIC CONTAMINATION

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One of the areas of concern in spacecraft contamination is the deposition of charged particles on the satellite surfaces. These particles are attracted to surfaces by electrostatic forces between the particle and the charged surface of the satellite. The source of particles can be the natural environment, charged particles emitted from the spacecraft, or outgassing particles ionized by electric fields around the satellite. The result of this deposition can be a significant degradation of the surface which can disrupt science measurements or performance of the thermal system.

To study this phenomenon requires an analytical tool that will predict surface charging on any spacecraft surface due to the environment, predict changes due to thermal operating conditions, generate fields surrounding the spacecraft, and trace particle trajectories to determine if they return. Such a tool has been generated as part of the joint AF-NASA Spacecraft Charging Investigation. This tool is called NASCAP, an acronym for NASA Charging Analyzer Program.

NASCAP has been developed to study the behavior of any three-dimensional body subjected to the space environment. It will predict surface charging on all surfaces as a function of time. As an output of the program, the fields surrounding the spacecraft are generated and all particle trajectories can be predicted. Hence, the tool can be used for studying electrostatic contamination.

As an example of the use of this program to study contamination, a preliminary model of the Spacecraft Charging At The High Altitudes (SCATHA) spacecraft has been developed. The fields surrounding this spacecraft due to the nominal environment and the substorm charging environment have been generated. Typical particle trajectories have been plotted. The implication of these results on electrostatic contamination will be discussed.

The NASCAP program is currently operational on UNIVAC machines. Modifications required to operate the program on CDC machines are presently underway. The computer program is currently being revised and upgraded to improve the operating characteristics. The future capabilities of the program will be discussed.

SATELLITE SELF CONTAMINATION EXPERIMENTS

by

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Gaseous emissions from a spacecraft modify the orbital environment and degrade the observations of distant radiation sources. These emissions also provide contamination fluxes induced by self scattering and scattering with ambient particles.

Experiments were carried out on the orbiting Atmospheric Explorer-D Satellite (AE-D) to verify the calculated return fluxes of a neon source. Known rates of neon were emitted in the direction of the velocity vector on command from the MRMU (Molecular Return Measurement Unit). At 250 km the neutral mass spectrometer indicated a total neon return flux of 2.46×10^{-2} times the emitted flux. The calculated fraction was 1.23×10^{-2} including 9.14×10^{-3} for the altitude independent self scatter. The pressure gages indicated pressures less than 7×10^{-6} torr at altitudes from 161 to 210 km. The maximum pressure for 161 km orbit was calculated as 7.4×10^{-7} torr.

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Backflow Contamination From Solid Rocket Motors

By

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Contamination from plumes of solid rocket motors have been suspect for the anomalous temperature behavior of many spacecraft systems and subsystems. The prediction of the contamination of a surface exposed to the effluent of a motor requires the knowledge of the contaminant flux arriving at a surface. There are approximate methods for determining flow fields and the subsequent transportation of plume-borne contaminants extending hundreds of nozzle-exit radii downstream from a nozzle exhausting into a vacuum. Existing plume prediction methods fail to give a satisfactory account of exhaust products upstream (back flow region). The plume expansion is limited in these mathematical models by the Prandtl-Meyer angle at the exit Mach number.

In an effort to find supporting evidence for this phenomena a significant number of spacecraft experimenters and designers, along with noted solid rocket motor experts, were surveyed. The survey was limited to those experimenters and designers whose systems or subsystems might have been subjected to SRM plume effluents (i.e., apogee kick motors). The results of the survey, along with the author's interpretation and conclusions, will be presented. These findings will be particularly meaningful to those concerned with modeling the effects of solid rocket motors on critical spacecraft surfaces or on scientific experiments that could be directly or indirectly affected by molecular or particulate contamination.

Contamination Mechanisms of Solid Rocket Motor Plumes

By

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A new generation of space satellites require freedom from contamination upon insertion into final operational orbits. There is concern that the combustion plume from solid rocket motors (RMS's) such as the Interim Upper Stage (IUS) units, which will be employed to deliver payloads into space after deployment from the STS shuttle craft, may be a source of significant contamination.

Although payloads are located forward of the SRM's, evidence suggests that recirculation of nominally trivial amounts of plume products flowing 180° to the direction the rocket exhaust occurs during the rocket firing and, further, that these recirculated products deposit on sensitive thermal control surfaces of the payloads to degrade their effectiveness.

The recirculation phenomenon may also be present in liquid rocket motors, but their combustion products, unlike solid rocket motor combustion products, are predominantly volatile and do not constitute a potential contamination hazard.

In order to assess this phenomena for solid rocket motors, several mechanisms were postulated to explain the recirculation. They are:

1. Charge separation - the plume products assume a charge opposite to the SRM and/or payload structures by virtue of triboelectric effects or thermal ionization.

2. Inter-plume collision - some faster moving species collide with slower moving ones, resulting in particle vectors counter to the plume direction.

3. Nozzle boundary turbulence effects - turbulence at the nozzle wall-plume interface results in a boundary layer flow that conforms to the nozzle surface and ultimately flows in a direction counter to the plume direction.

4. Shock wave effects - effects occurring at the plume boundaries and during shutdown of the SRM firings propel plume products in a forward direction.

Analytical computer models developed to simulate these mechanisms and predictions of their corresponding potentials for causing recirculation contamination of space system surfaces are presented.

CONTAMINATION AND HEAT TRANSFER PROBLEMS RESULTING FROM HIGH EXPANSION OF THE SUBSONIC BOUNDARY LAYER FLOW IN THE VOYAGER TE-M-364-4 SOLID ROCKET MOTOR

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ABSTRACT

Mass and volumetric constraints dictated that the Voyager Spacecraft science instrument package be located within twenty inches of the TE-M-364-4 Solid Motor exit plane. Although the science was located 100 degrees away from the nozzle centerline there was still concern about the flow from the subsonic boundary layer overheating and contaminating the instrument surfaces. Since preliminary extimates indicated there could be a severe problem it appeared that plume shields and covers would have to be employed. However, additional information was needed to specify the thickness, location and degree of wrap-around. One of the more difficult problems was how to estimate the mass flux, since standard Method of Characteristic solutions weren't valid and scaling test data obtained in the high vacuum MOLSINK test facility seemed to indicate surface and the amount that would flow around the edge of the shield and impinge on the instruments also had to be calculated. To solve this latter problem, a contract was let to TRW to use their Monte Carlo program. Confirmation was then obtained with plume instrumentation during the first Block V launch. This paper discusses the plume model, applicable MOLSINK test results, the TRW predictions and the Block V and Voyager flight results.

SPACE SHUTTLE PLUME CONTAMINATION

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A majority of the manned spacecraft and heavyweight satellites use earth storable bipropellant propulsion systems for attitude control and orbit change manuevers. These propulsion systems have a demonstrated high performance and reliability but the rocket engine combustion products are much more complex than the products of hydrazine monopropellant decomposition or of cold gas propulsion. These products of combustion can deposit or condense on surfaces in the vicinity of the rocket engine, and can cause a degradation in system efficiency.

Tests conducted in support of the Apollo and Manned Orbiting Laboratory using production rocket engines and spacecraft surfaces showed that rocket engines which were designed for minimum injector manifold volumes and highest possible combustion efficiency minimized the potential for contamination. In addition surfaces which are impinged upon by combustion products were effectively protected by line of sight barriers and by heating the surfaces.

The Space Shuttle Orbiter "plume contamination characteristics" are varied because of the diverse modes of operation and as a result, a series of studies were undertaken to determine what operating modes for both the thrusters and the system would minimize the potential contamination. Studies were also conducted to identify and characterize changes in surface properties. The results of the studies indicate that plume transportated contamination does not impinge or condense on the surfaces of the orbiter, but that some potential does exist for the flow of fuel film contaminate down the wall of the exhaust nozzle and off of the nozzle lips when short pulse widths and cold combustor walls are encountered.

Further studies involving the interaction of the Orbiter with the payloads during and after deployment indicate that the devices presently used to protect the sensitive surfaces prior to operational deployment are adequate for the shuttle deployment mechanisms.

BIPROPELLANT MOTOR PLUME CONTAMINATION STUDY

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ABSTRACT

There is ample evidence of rocket motor exhaust plume contamination at large angles relative to the plume centerline forward of the nozzle exit plane. Even though the CONTAM II plume contamination model has not been verified and is unable to handle such large angles, it has been the accepted tool for analytic predictions of plume contamination in major programs such as Space Shuttle/STS. Hence it becomes very important to study contamination in the plume backflow region, to verify the mechanisms for the transport of exhaust products into the backflow region, and to develop the analytic capability for predicting plume contamination in this region. Such studies require an experimental data base including complete characterization of the nozzle exit plane properties of the rocket motor.

This is the first report on an experimental program to measure the mass flux in the backflow region of a 5 lbf bipropellant motor, at angles up to 120° with respect to the plume centerline, using temperature compensated quartz crystal microbalances. The measurements are being conducted in a high vacuum cryogenic chamber at AEDC. The addition of new GHe and LHe cryopanels provides a blank-off pressure in the 10^{-7} torr range and maintains the background pressure in the 10^{-5} torr range while pulse firing the motor (25-100 msec pulse width, 1-10% duty cycle). Chamber recovery time is a few tenths of a second.

Several motor configurations and operating conditions will be compared for potential contamination effects. Variations include: injector - 0° and 45° splash plate; combustion chamber - 2 in cylindrical, 1.5 in cylindrical, and 2 in conical; nozzle area ratio - 50:1 and 100:1; O/F - 1.4, 1.6, and 1.8; chamber pressure - 75, 100, and 125 psia; pulse duty cycle - 1%, 5%, 10%, and continuous.

In addition to the QCM's more extensive diagnostics will be used to fully characterize the plume constituents, to measure exit plane properties, and to carefully monitor nozzle lip effects. Electron beam fluorescence, IR transmittance, witness plates, cryogenic mass spectroscopy, Raman scattering, and Mie scattering are planned.

EXHAUST PLUME CONTAMINANTS FROM A HYDRAZINE MONOPROPELLANT THRUSTER

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ABSTRACT

An experimental study of the exhaust plume characteristics of a 0.44 n thrust monopropellant hydrazine thruster with an aged catalyst bed (over 200,000 pulses) has been performed to determine both the gas dynamic and contamination properties of the exhaust. The study was conducted in a cryogenically pumped vacuum chamber which maintained high vacuum conditions (simulated pressure altitudes greater than 94 km) for all modes of engine operation. The exhaust diagnostic systems employed in the investigation included quartz crystal microbalance, quadrupole mass spectrometer, laser-Raman scattering, laser-Rayleigh scattering, electron beam fluorescence, electron beam flow visualization, and sample collection. In addition, traditional engine performance parameters were measured on the 0.44 n thrust Hamilton-Standard thruster which was operated primarily in a pulsed mode with a 0.1-sec on/10.0-sec off duty cycle.

The engine, which was installed on a three linear degree of freedom traversing cart for plume mapping, was operated with standard monopropellant grade hydrazine over a range of thrust values from 0.44 n to 0.96 n and at initial catalyst bed temperatures of 367K, 478K and 589K. Exemplary data for the exhaust plume properties, species densities and rotational temperature, are presented but the only detailed results are given for the forward flow contamination data obtained with the mass spectrometer and quartz crystal microbalance (QCM). Mass spectrometer data are presented which demonstrate the centerline variation of ammonia and hydrazine for various thrust levels, bed operating conditions and time of operation. High concentration of hydrazine was noted for some operating conditions, sometimes as high as 38% mole fraction for initial pulses. Also intrapulse data are presented which quantitatively demonstrate catalyst bed performance and occasional large variations in exhaust products. The QCM was operated over a range of surface temperatures from 110K to 190K and data are presented which demonstrate the relative contribution to contaminant deposition of trace species and raw fuel as well as quantitative deposition rate information for cold surface contamination.

Finally, complete documentary evidence is presented which indicates the possibility for very significant increases in contamination levels from non-spent engines with only minimal (10%) degradation in overall engine performance. This phenomenon was observed for the engine studied in this investigation and occurred over a very short time span with an order of magnitude increase in contamination levels. Details of the subsequent experimental investigation of this phenomenon are included.

The work reported herein was conducted for the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), by ARO, Inc., a Sverdrup Corporation Company, operating contractor for the AEDC. Further reproduction is authorized to satisfy needs of the U. S. Government.

DESIGN OF A PROPULSION SYSTEM TEST FACILITY TO STUDY ROCKET PLUMES IN THE SPACE ENVIRONMENT

L. F. Molinari

A NASA project has been initiated at JPL for the design and fabrication of a propulsion system test facility for the purpose of testing various types of propulsion systems in the space environment. The Propulsion Contamination Effects Module (PCEM) Spaceflight Experiment is being designed for installation in the payload bay of the Space Shuttle Orbiter. The objectives of the experiments are to measure exhaust plume backflow efflux (mass and constituents), core flow properties, and electrical charge buildup. The measurements will be made from high thrust (up to ∿1000 lbf) chemical and low thrust (∿30 mlbf) electric propulsion systems.

The experimental data will be used to demonstrate the ability of analytical models to predict the levels of contamination, forces, heat transfer, and surface charging effects anticipated on a spacecraft employing these propulsion systems. The modeling data available for spacecraft design is considered limited because of the necessity for extrapolation of empirical data from mini-thrusters tested in vacuum chambers. The concept of the PCEM is a further extension of the work that JPL has been doing for a number of years for both NASA and the Air Force relative to plume studies in the JPL Molsink facility. These earthbound experiments are limited and the next logical step is to experiment in the actual space environment to acquire the necessary data for plume definition, including plume backflow and propulsion contamination effects.

Design of the PCEM facility includes various types of sensors for measuring a number of parameters. Included in the instrument measurement systems are temperature controlled quartz crystal microbalances and a mass spectrometer. Instruments will measure the mass flux in the far field of the nozzle plume with emphasis on the backflow region. Existing theories for prediction of the far field of a plume are inadequate for large angular departures from the plume axis. PCEM measurements will provide data for off-axis angles as large as 140° (i.e. in the backflow region). Since this region is well behind the exit plane, it is of particular interest to those concerned with instrument contamination. Sensitive spacecraft surfaces are usually located in the region affected by the backflow.

The initial PCEM configuration is designed to accommodate a ∿25 lbf monopropellant hydrazine propulsion system currently being developed by MSFC. Later design modification kits will modify the PCEM to accommodate other propulsion systems. These are: N_2O_4/MMH ∿870 lbf liquid bipropellant Shuttle RCS system provided by JPL; 8 cm and 30 cm ion drive engines provided by LeRC; the ∿1000 lbf solid rocket motor provided by JPL; and a GO_2/GH_2 ∿25 lbf gaseous bipropellant system provided by LeRC.

ABSTRACT

SHUTTLE INDUCED INVIRONMENT CONTAMINATION MONITOR

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The Induced Environment Contamination Monitor (IECM) is a set of ten instruments integrated into a self-contained unit. The IECM is scheduled to fly as part of the Demonstration Flight Instrumentation (DFI) on Shuttle Orbital Flight Tests 1 through 6 and on Spacelabs 1 and 2 as part of the Verification Flight Instrumentation (VFI).

NASA began strong manned mission contamination control efforts for the Skylab mission and, recognizing the possible limiting effects induced contamination might have on sophisticated observational programs planned for the 1980's, committed to an effort to insure that the induced environment would not be a problem.

The purpose of the IECM is to measure the actual environment to determine whether the strict controls placed on the Shuttle system have solved the contamination problem.

The IECM will operate during prelaunch, ascent, on-orbit, descent, and post-landing. The on-orbit measurements are molecular return flux, background spectral intensity, molecular deposition, and optical surface effects. During the other mission phases dew point, humidity, aerosol content, and trace gas will be measured as well as optical surface effects and molecular deposition.

The ten instruments are: Dew Pointer, Humidity Monitor, Cascade Impactor, Optical Effects Module, Passive Sample Array, Thermoelectric Quartz Crystal Microbalance, Air Sampler, Mass Spectrometer Camera/Photometer, and Cryogenic Quartz Crystal Microbalance. Each instrument is briefly described, and its measurement limitations are compared to the contamination control requirements.

Efforts are being made to operate the IECM using the Shuttle Remote Manipulator System to directly measure off- and outgassants as well as column densities. This would be accomplished by actually picking up the IECM and moving it about the Shuttle for various measurements.

DESCRIPTION OF THE MASS SPECTROMETER FOR IECM

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A quadrupole mass spectrometer is described which will be used to make the molecular return flux measurements on the Induced Environment Contamination Monitor (IECM) for Shuttle and Spacelab. This mass spectrometer is being developed for NASA by the University of Michigan Space Physics Research Laboratory. The basic quadrupole has a sensitivity of 2×10^{-3} counts/sec/particle/cm^3 for atomic masses between 2 and 150. A unique collimator utilizing an activated gettering material is attached to the quadrupole to provide 10 degree half angle (0.1 steradian) collimation. A digital data system is used to accumulate counts up to 17 million over integration times of either 0.2 or 2.0 seconds. Calculations using the results of post assembly testing will be presented to show how closely this instrument meets the requirements specified by the Contamination Requirements Definition Group. Final calibration of the mass spectrometer will be done in orbit. The effectiveness of the collimator will be measured in orbit by slowly scanning the mass spectrometer through the velocity vector of the spacecraft and measuring the ambient gas. The density and energy of these molecules is known very well and will be a calibration factor. To arrive at realistic values of molecular column density, one needs to know the scattering cross section of ambient gas at orbital velocities on Shuttle generated molecules. This will be accomplished by releasing a well defined beam of isotopically labeled gas (D_2O^{16} and Ne^{22}) while the Shuttle again sweeps through a full circle with respect to the velocity vector. A modification to the IECM for the Spacelab II mission will be to provide a continuous monitoring of the water peak to the payload specialist in Spacelab. This information will prevent opening of certain instruments if a dangerous level of water molecules exists.

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QUARTZ CRYSTAL MICROBALANCE SYSTEMS FOR SHUTTLE CONTAMINATION MEASUREMENTS

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A simple quartz crystal microbalance is of limited value in monitoring surface contamination on spacecraft because power dissipation raises its operating temperature several degrees above the ambient. The amount of contamination adsorbed on a surface is highly temperature dependent and the elevated temperature of the microbalance will significantly reduce the amount of contamination it adsorbs. Generally, a quartz crystal microbalance will indicate a lower level of contamination than the amount that is actually present. Fundamental studies of contamination require the control of surface temperature over a range common to the space environment so that rates of adsorption and desorption can be measured and the exponential decay time constant for various contamination species can be determined. This type of data is important to the understanding of interaction of the induced Shuttle contamination with the upper atmosphere and the degree to which surfaces will be contaminated.

Two different types of microbalance systems have been developed for Shuttle using active and passive temperature control. The active system uses thermoelectric devices with temperature bridges and servos for automatic temperature control. This system is called the Temperature-Controlled Quartz Crystal Microbalance (TQCM). It consists of a controller and five removable sensors. Five sensors are used to give the spatial distribution of contamination in addition to measuring surface contamination as a function of temperature. Each sensor can be set by ground command at five predetermined temperatures between −60 and +60°C ± 1°C or free run. Frequency of each sensor is readout digitally to ± 1 Hz giving a contamination loading sensitivity of 1.56×10^{-9} g/cm^2. Maximum sensor loading is approximately 3×10^{-4} g/cm^2. The operating temperatures of each sensor as well as its heat sink are monitored.

The other microbalance system uses passive cooling. It monitors highly-volatile contaminants using a radiant cooler to reach cryogenic temperatures. This system is called a Cryogenic Quartz Crystal Microbalance (CQCM). It consists of a controller and sensor head. The sensor head contains two removable sensors. One sensor operates below the freezing point of water and monitors contamination including water vapor. The other sensor is heated and monitors contamination background and provides a reference from which the density of induced water vapor cloud surrounding Shuttle can be determined. Heaters in each sensor and the radiant cooler can be activated by ground command for ice removal. The temperature of each sensor is monitored between −153 and +37°C ± 1°C. Sensor mass sensitivity and readout are the same as the TQCM.

Considerations in the Use of QCM's for Accurate Contamination Measurement

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The Quartz Crystal Microbalance (QCM) has been used on a number of spacecraft for the qualitative measurement of contaminant flow to spacecraft surfaces. For truly diagnostic work and quantitative measurement, the QCM must be understood as a complex flow system with both condensation and evaporation of gases occurring on the sensing crystal and surrounding QCM entrance surfaces, with the added complication of entrance flow conductance factor considerations. Relationships are developed for both diffuse and directed molecular flow to a QCM for the quantitative determination of free stream molecular flux as a function of QCM crystal temperature, entrance conductance factors and contaminant vapor pressure. From these relationships, guidelines of required crystal temperature for accurate contaminant measurement are given.

Various spacecraft applications of the QCM include a varying thermal radiation flux to the sensing crystal such as installations in which the spacecraft rotates and the QCM receives direct insolation. The thermal stress induced in the crystal produces an anomalous frequency shift. Work is described on doublet crystal QCM's which eliminate not only this transient effect but also any frequency shift due to temperature gradients between the sensing and reference crystals since in the doublet they are located on a single quartz blank. Investigation reported includes crosstalk between the sensing and reference doublet electrodes and the effect of quartz crystal size on measurement sensitivity and crystal temperature.

EVALUATING A CONTAMINATION HAZARD WITH A RESIDUAL GAS ANALYZER

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This paper describes the use of a residual gas analyzer to evaluate a contamination hazard to a sensitive spacecraft instrument during a test in a vacuum chamber. An approach for estimating the sensitivity of an uncalibrated residual gas analyzer for a specific contaminant in situ is presented. The approach involves a knowledge of the vapor pressure characteristics of the contaminant and of its mass spectral pattern. Using this together with information on the temperature of a surface of concern, an estimate of the contamination hazard is developed.

Post test measurements of the test item indicated that the hazard remained within safe limits. Suggestions for improving upon the technique are presented.

MOLECULAR CONTAMINATION STUDIES BY MOLECULAR BEAM SCATTERING

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Optical and thermal control surfaces of spacecraft components and experiments have been shown to be sensitive to the effects of contaminant deposition. For the studies of degradation effects by various organic films, the influences during prelaunch testing in space simulation chambers and the effects of contamination during missions have to be considered. The purpose of this paper is to report the capability of molecular beam interaction with a solid surface detecting molecular contamination of a surface by an organic film. The measuring principle to be applied is based on the change of the scattering distribution of a molecular beam from a clean surface and from a contaminated surface.

A molecular beam source and a phase sensitive measuring setup were designed, built, and installed into a vacuum chamber assembly where a vapor effusion source is attached for the deposition of the molecular contamination films. The He or N_2 molecular beam was directed to a Platinum surface which was clean or contaminated by an organic film from the vapor effusion source filled with DC 705 pentaphenyl trimethyl siloxane diffusion pump oil.

The scattering of He and N_2 molecular beams from the Platinum surface as a function of scattering angle was measured. In the surface temperature range of 39 to 110°C the scattering distribution is approximately diffuse. For surface temperatures above 185°C, a specularly directed distribution is found. The reversible transition between diffuse and specularly directed scattering at a surface temperature of approximately 200°C can be explained by removal of absorbed layers because of the background pressure. The maximum scattered beam intensity as a function of surface temperature starts to increase at an approximate temperature of 160°C and increases in the entire measured temperature range up to 210°C. After operation of the vapor effusion source and contamination of the surface by DC 705 (vapor pressure $5 \cdot 10^{-9}$ torr), a change of the scattering distributions was measured. The increase of the scattered beam intensity starts after the contamination at a surface temperature of 200°C (160°C before contamination). At a surface temperature of 200°C, the ratio between the maximum scattered beam intensity and low temperature beam intensity is 1.04 (1.50 before contamination). For reaching a value of 1.5 for this ratio before contamination, a surface temperature of 200°C was necessary but after contamination the necessary surface temperature was 358°C. After operation of the vapor effusion source at a vapor pressure of $5 \cdot 10^{-8}$ torr, the scattering distribution changes from an approximately diffuse distribution with a specularly directed portion (surface temperature 41 to 232°C) to a distribution which is very close to a cosine function (surface temperature 88°C).

The capability of molecular beam scattering for the detection of contamination is indicated by the following possibilities: Measurement of the change of the scattering distribution or measurement of the change in the temperature dependence of the maximum scattered beam intensity.

SPACECRAFT TEST CHAMBER CONTAMINATION STUDY

AEDC MARK I FACILITY

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AEDC Division
A Sverdrup Corporation Company

and

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ABSTRACT

Recent results of a contamination study in the Arnold Engineering Development Center Mark I space simulation chamber are presented. Attenuated total reflection (ATR) plates, thermal control surface samples, and quartz crystal microbalances (QCM) were employed to measure contaminants and condensible gases during an extended chamber evacuation. An automatic particle counter was used to measure airborne particle density when the chamber was at atmospheric pressure. Temperature of the ATR plates during chamber operation, was between 150 and 200°K. One QCM was temperature controlled to a temperature of 283°K; the other QCM operated at 135°K. After chamber repressurization, the ATR plates were scanned in the 2 to 15 μm wavelength region. Resulting spectra indicated a coating of diffusion pump oil (DC 704) at a concentration level just above the limit of detectability. The cold QCM recorded deposition during chamber evacuation. This deposit sublimed during chamber warmup at a temperature of 170°K, the sublimation temperature of water. Since neither QCM indicated a mass addition after chamber repressurization, we have used the 1.7×10^{-7} gr/cm^2 minimum detectable mass of the QCM as an upper limit for the mass of silicone oil collected on the ATR plates. This upper limit corresponds to two monolayers of oil for a twenty-nine-day evacuation period. The thermal control surface samples showed no change in IR spectral reflectance during the same twenty-nine-day chamber evacuation. Particle counts were taken during periods when the Mark I chamber was at atmospheric pressure. Particle densities measured for particles larger than 0.5 μm were nominally 6000 particles/ft^3. Particle density for particles larger than 5.0 μm were nominally 15 particles/ft^3. The airborne particle contamination in the Mark I chamber (at atmospheric pressure) was therefore below that of a class 10,000 clean room, as specified by Federal Standard 209.

Ground Contamination Monitoring Methods

By

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The majority of present day space vehicles are subject to prelaunch thermal vacuum testing. During testing there is a large risk of contaminating the payload from polymeric materials in the chamber and from backstreaming of vacuum pump oils. Optical and thermal control surfaces are particularly sensitive to the effects of contaminant deposition. The cleaning of surfaces contaminated during testing is often difficult and extremely expensive.

As part of an on-going program at Aerojet to study contamination phenomena, a design concept has been identified for a contamination monitor for ground environment application. These environment monitors (witness samples) would follow along with the spacecraft during all phases of handling (e.g., manufacturing, test, etc.) up to the launch phase. This practice would enable one to easily define the quantity and species of any contaminant and at what time it attached itself to the spacecraft.

Two types of monitoring methods will be described - a KRS-5 prism and a front surface quarter wave coated mirror. IRS (Internal Reflectance Spectroscopy) measurements of the KRS-5 prisms from 2.5 to 30 μm will allow determination of contamination film thickness, calculation of real and imaginary index of refraction, and general species identification via refractive index signature analysis. The $\lambda/4$ coated mirror accurately indicates the presence of thin contaminant films and any change in spectral reflectance from 0.25 to 2.5 μm. Changes in solar absorptance (α_s) and real index of refraction signature can be derived from the mirror measurements. A more detailed description of these measurement techniques, along with sample spectra of deposited contaminants, will be presented.

The utilization of both types of monitors would provide invaluable information in understanding during what phase of manufacture and test contamination is occurring, how thick the contaminant is, if cleaning is required, and what the subsequent effects would be to the radiative properties of the spacecraft.

TITLE: ASSEMBLAGE ANALYSIS - IDENTIFICATION OF CONTAMINATION SOURCES

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ABSTRACT

It has been found that contamination samples of less than one milligram often contain a sufficient variety of particulate types to reconstruct a history of contamination exposure. This approach involves the use of analytical light microscopy, and related techniques, to identify source-characteristic assemblages of particulates. Sources are identified as belonging to one of four major categories: auto-generated, function generated, facility generated, or activity generated. The first two indicate system reliability and design-operational environment compatibility. The last two involve production related problems of facility control or failure to properly isolate the part from externally generated contaminates.

Sources cannot generally be identified through the identification of a single particle species, but only through a combination of species in specific size ranges and present in "reasonable" proportions with respect to other members of the assemblage. This paper presents the basis for criteria used to identify an assemblage and the analytical support required to evaluate such a sample. Examples of common assemblages are given as well as precautions against conclusions based on too few members of an assemblage. A brief final statement is included regarding the benefits of this type of program support.

SPACE GRADE CHEMICALLY FOAMED SILICONE ELASTOMERS

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Chemically foamed silicone elastomers have been shown to be excellent thermal protection materials for many space applications as well as for listing entry heating conditions encountered during re-entry. For instance, for the lower temperature upper surface of the Space Shuttle Orbiter, re-use capability has been demonstrated, in ground tests, conducted at heating times of thirty minutes per cycle at surface temperatures of up to 800°F for a total of 100 cycles.

One of the main disadvantages of conventional silicones for space application is that under the normal cure and postcure conditions, the elastomers may contain as much as 4 - 6% of low molecular weight oils which can volatilize under the low pressures encountered in the space environment and recondense on surfaces where the undesirable contamination may be harmful.

Space grade silicones are available which meet the outgassing and recondensible materials requirements when given the normal cure and postcure treatments. However, because of the stripping treatment used in their preparation, these materials are very expensive. Their use as starting materials for the preparation of foams would be extremely uneconomical.

It has been found that chemically foamed elastomers can be prepared from conventional silicones, and when these are subjected to a thermal vacuum stripping after the normal cure and postcure treatments, meet all the weight loss and volatile condensible materials criteria required for a space grade material.

The resulting low outgassing foams are much more economical than would be the foams fabricated from the space grade starting materials, and possess physical and thermal properties similar to or superior to those foams which have not been given the stripping treatment.

Treatment conditions, weight loss data and typical thermophysical properties of both the conventional and stripped foams are given in the paper. Two types of foams are discussed: (a) A series which contains inorganic fibers to promote the formation of a hard char and to enhance char retention during reentry ablation. (b) A series which does not contain inorganic fibers and which is intended to be used primarily as insulation for both low and high temperature applications.

ABSTRACT

"INVESTIGATION OF CONTAMINATION PREVENTION TECHNIQUES FOR A CRYOGENICALLY COOLED TELESCOPE IN EARTH-ORBIT"

by M. A. Hetrick
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This paper reports on the status of a study to investigate the use of a helium gas purge to provide protection to cryogenic surfaces inside an earth-orbiting infrared telescope.

The technology of cooled infrared orbiting telescopes now offers a unique opportunity for astronomers to probe more than 30 times deeper into our universe than previously possible with ground based observatories. A potential limitation however, will be contamination effects.

Condensation of desorbed gases, outgassing polymers and ambient oxygen on mirrors and baffles which are cooled to 15^{o}K can compromise the otherwise enhanced performance of an orbiting IR system. In an attempt to alleviate this problem, it was suggested that a continuous flow of helium gas out of the telescope barrel be employed to purge contaminants from the telescope.

A subscale model of a typical IR telescope equipped with a helium purge system was studied under simulated orbital conditions. Helium flow rates, injection temperatures and flow patterns were varied to determine the purge effectiveness against four contaminant conditions: a) DC92-007 outgassing molecules at thermal velocities, b) H_2O at thermal velocity, c) O^+ and O_2^+ at 1-9 km/sec, d) DC92-007 outgassing molecules back scattered by high velocity O^+ and O_2^+ species.

Both the subscale configuration and the full scale Shuttle IR Telescope Facility (SIRTF) were analytically modeled. A single collision return flux analytical model was used to develop scaling criteria and project the subscale results to the full scale configuration.

Recommendations are made for further analytical and experimental studies of contamination abatement techniques which utilize active gas purge systems. This work was supported by NASA Ames Research Center, Moffet Field, California.

EFFECTIVENESS OF THE SHUTTLE ORBITER PAYLOAD BAY LINER AS A BARRIER TO MOLECULAR CONTAMINATION FROM HYDRAULIC FLUIDS

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The payload bay of the Shuttle Orbiter is designed to contain numerous experiments that are expected to be extremely sensitive to even slight amounts of molecular contamination. Although the effects of molecular contamination vary somewhat for different molecular species, high molecular-weight components such as oils and hydraulic fluids can result in significant impairment of operation or degradation of experiment performance. This is particularly true in the case of experiments utilizing optical surfaces where a single monolayer of a contaminant could completely compromise the experimental objectives.

In the present Shuttle Orbiter configuration, a number of hydraulic lines (required to operate the elevons, main engine gimbal, landing gear brakes and steering, etc.) are routed below the payload bay. A liner consisting of Teflon-coated beta glass has been placed between the fluid lines and the payload bay. The liner was designed primarily to prevent particulates generated in the mid-fuselage section from entering the payload bay; its effectiveness as a barrier to leaked hydraulic fluids was unknown.

To evaluate the effectiveness of the liner as a barrier to molecular contamination, an experiment was conducted in a small thermal-vacuum chamber. A molecular generator was designed to simulate a "typical" molecular flux; flux rates were varied by controlling the fluid temperature. The hydraulic fluid used in the experiment was manufactured per specification MIL-H-83282A and actually consisted of a blend of several different fluids (average molecular weight 421). A thermoelectrically-cooled quartz crystal microbalance was used to measure the molecular flux density for several collection surface (crystal) temperatures to establish the effective "sticking coefficient" for the fluid. Mass desorption rates as a function of collector surface (crystal) temperature are presented. The effectiveness of the payload bay liner as a barrier to molecular contamination resulting from leaks of hydraulic fluid is established and discussed. Mechanisms potentially responsible for the transmission of hydraulic fluid through the glass cloth payload bay liner are reviewed.

PARTICULATE CONTAMINATION - TIE-DOWN WITH PARYLENE C

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Entrainment of loose conductive particles within microcircuit packages has been documented as a persistent problem. Occasionally, small, usually microscopic, pieces of metal remain inside hermetically sealed devices despite strenuous efforts to assure cleanliness during manufacturing operations. The problem is of particular concern when hybrid circuits are employed on spacecraft, where stresses encountered during launch can cause previously undetected particles to migrate from innocuous positions to places resulting in electrical shorts. Measures taken, both to test packaged devices for the presence of these particles and to remove them have included among other means, radiographic examination and particle impact noise detection (PIND). Still, small particles can escape notice and non-conducting particles, especially in PIND testing, can cause part rejection.

A positive solution, employed successfully for NASA's Centaur electronics and under evaluation by military agencies, involves a plastic coating, Parylene C. At a thickness of 0.1 mil this material effectively encapsulates and seals (ties down) the offending particles in place, preventing further movement to positions causing electrical malfunction. Additionally, the parylene coats and thus insulates all surfaces inside the package, so that larger particles, should they manage to break loose, cannot impair electrical performance. Additional process detail will be presented in this review paper.

In contrast to conventional liquid resins, parylene coatings are formed by pyrolysis of high purity di-p-xylylene in a vacuum environment, followed by deposition and spontaneous polymerization on cool surfaces. The process resembles vacuum metallizing except that the parylene monomer molecules, while in the gas phase, surround the object to be coated and cause growth of the coating to occur uniformly on all surfaces.

Certain unique features make the parylene system suited for particle tie-down: The ability of the monomer gas to penetrate holes and thus coat the inside of microcircuit packages; the ability of the coating to conform precisely to convoluted surfaces including wire bonds and the underside of inverted chip devices; its ability to cover thoroughly at thicknesses of 0.1 mil and below.

Compatibility of Parylene C coatings with active and most passive devices has been demonstrated. Documentation of these and the exceptions will be given.

AFGL INFRARED SURVEY EXPERIMENTS CLEANING PROCEDURE

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ABSTRACT

The Air Force Geophysics Laboratory HI STAR sounding rocket program was designed to provide an infrared survey of the celestial sphere. The effect of particulate contamination upon infrared experiments in space has long been recognized and payload handling techniques have been developed to minimize the possibility of dust and dirt in the experimental environment. The survey payload was designed therefore to facilitate removal of all traces of possible external contaminants either by containing them inside fully enclosed areas or removing them from exposed sections. The clean area was isolated from the contaminated area by "O" ring bulkheads both fore and aft and from the outside by ejectable doors.

Special development procedures were employed for the cleaning and drying of the super polished mirrors in the infrared radiometer, and special cleaning processes were used for small parts and tools used in the clean room.

An ultraviolet lamp was used to see lint, dust and other fluorescent material. Precise cleaning of all surfaces to include the fluorescent material effectively cleaned the payload.

A step by step method of payload cleaning is described from the nose tip and stellar aspect system to the separation joint above the rocket sustainer. Special rules for all operations in the clean room were evolved and adhered to at all times during cleaning.

Following cleaning, clean bagging and debagging procedures prior to launch and during payload operation in the launch tower were devised.

In ten launches of the HI STAR program ninty percent of the sky was surveyed and some 3200 celestial objects located. Final result was a catalogue of the sky in four different wavelength regions.

PARTICULATE CONTAMINATION CONTROL FOR THE VIKING AND VOYAGER UNMANNED PLANETARY SPACECRAFT

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Particles released during the flight of planetary spacecraft can result in either unacceptable performance of science instruments or in mission operations problems caused by particles interfering with the celestial sensors. Because of planetary protection requirements for spacecraft flying to planets of biological interest, a high degree of exterior particulate cleanliness is also desirable to reduce the likelihood of the accumulation of microbial burden on spacecraft surfaces. To minimize the accumulation of particulate matter on the spacecraft exterior surfaces, the Viking and Voyager projects contamination control programs consisted of establishing cleanliness requirements for facilities, equipment, and personnel. This paper discusses the effectiveness of these programs during the prelaunch operations at Cape Canaveral.

The final assembly and checkout of the Viking and Voyager unmanned planetary spacecraft occurred in Class 100,000 (or better) cleanrooms. Following spacecraft encapsulation, the payload was continuously subjected to Class 100 air during transport, hoist, and on-pad operations. Several different particulate determination approaches were used to verify not only spacecraft surface cleanliness but also air cleanliness. These included visual inspection of surfaces with and without magnifying aids, collection of visible surface particles for chemical analysis, light scattering particle measuring devices, and specially developed samples for monitoring exhaust air.

Visual inspections of spacecraft surfaces occurred periodically during the prelaunch operations. The contamination control inspection team would either certify cleanliness of the spacecraft or require additional cleaning. When it was necessary to identify the types of particles noted, particles were subject to chemical or spectral analyses.

Volumetric measurements of the air cleanliness of the cleanrooms and the encapsulated payload air conditioning systems were made using light scattering instruments. The data shows that the air cleanliness requirements for the cleanrooms and the air conditioning systems were satisfied. To obtain reliable measurements at high air velocities, as in the air conditioning ducts, specially designed isokinetic probes were used.

To evaluate air cleanliness during the transport and hoist operations of the encapsulated spacecraft, a pair of specially designed 40 mm disk samples were placed in the exhaust area of the payload. This technique proved acceptable for obtaining qualitative type of measurements during the five air conditioning changes during these operations as well as during on-pad operations if inlet air cleanliness became marginal.

Finally, in-flight bright particle occurrences as detected by the star trackers are used as an indirect indication of surface cleanliness. Based on comparisons with previous Mariner spacecraft, the Viking and Voyager spacecraft have had fewer bright particle occurrences.

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2nd Surface Mirror Cleaning and Verification

By

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The requirement that an advanced space satellite be free of contamination upon orbit insertion resulted in more stringent efforts to ensure maximum cleanliness at launch. Special techniques were developed to clean 2nd surface mirror thermal control radiator surfaces and ancillary procedures were invoked to verify their cleanliness level at launch.

Panels utilizing as many as 10,000 separate mirrors are used to achieve thermal control of the satellite system. Since the mirror panels can be exposed to a variety of potential contaminating environments during the satellite history of fabrication, assembly, ambient/vacuum testing, storage, shipment, and launch readiness, methods were studied to determine how best to clean and subsequently verify mirror cleanliness before launch. Whereas simple wiping of the surfaces with fabrics and appropriate solvents to achieve "visual clarity" may leave residues of as much as 1000 Å of surface contaminant, it was not evident how much improvement could be achieved by additional cleaning.

An effective cleaning procedure was established for 2nd surface-thermal-control mirrors using Auger Electron Spectroscopy to measure the contaminant residues on variously cleaned mirror panels. It was subsequently found that two sequential cleaning operations performed on individual mirror elements after the "visual clarity" condition had been obtained would achieve a minimal contamination level of less than 20 Å on the mirrors. In addition, a post-cleaning wipe-and-extraction procedure provided a means of verifying the level of cleanliness achieved. These techniques, currently employed to provide maximum 2nd surface-mirror cleanliness at launch of Aerojet space systems, will be described.

Verification of Spacecraft Surface Cleanliness

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Techniques used in determining the cleanliness levels (both particulate and non-volatile residue) of spacecraft surfaces will be discussed. These techniques have been used in manufacturing, test laboratory and launch pad environments. The non-volatile residue determination requires wiping a known area with a specially treated cloth moistened in a selected solvent blend. The wipe is then extracted to determine the non-volatile residue. Two control wipes are taken thru the same procedure except no surface is wiped; this allows one to determine the background of the verification procedure. The background as determined by extraction of the control wipes is approximately 50 micrograms, a factor of twenty below level A of MIL STD 1246A.

Three techniques for determining particulate cleanliness levels (photographic, witness blanket wash, and tape sample) will be described. The departure from the MIL STD 1246A size distribution (in a clean environment) as determined from these test results will be discussed.

SPACECRAFT PARTICULATE CONTAMINATION - A SURVEY

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ABSTRACT

Based on current NASA particulate control criteria for the STS as well as an increased DOD interest in the induced particulate environment of a spacecraft, there is a need to better understand particulate contamination and begin the development of a particulate model analogous to that of current molecular contamination models. This paper will present a survey of particulate data as related to various previous flown spacecraft programs. An interpretation of this data will be made as it relates to current spacecraft programs and criteria. The results of a number of independent studies relating to the production of spacecraft particulates will also be presented. An overview of the elements necessary for the development of a particulate model will be made. Key areas in the development of such a model will be addressed.

VI-2

Puncture Discharges in Surface Dielectrics as Contaminant Sources in Spacecraft Environments†

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Spacecraft at geosynchronous altitudes are subject to fluxes of high energy electrons which result in a charge build-up and subsequent electrical breakdown at dielectric surfaces. To simulate these effects a laboratory program at Colorado State University utilizes a high-energy electron beam incident upon thin sheets of silver-backed teflon. The circular teflon sample is mounted on an annular ring and is enclosed by a grounded aluminum box whose entrance aperture assures that the edges of the teflon sample are not directly irradiated by the electron beam. This arrangement facilitates the study of particle emission and material damage on both the front and back surfaces of the teflon sample.

Measurements are made of electron beam charging current, charging time, and surface voltage under static conditions while oscillographs in conjunction with transient current probes, fast response potential dividers, loop antennas, photomultipliers and charged particle detectors record the transient nature of the electrical discharges. The physical appearance of the self-luminous electrical discharges is recorded with time-integrated photography, and the resultant damage to the dielectric surface as well as the sites of discharge punctures through the dielectric layer are examined by means of scanning electron beam micrographs. The most prominent damage feature revealed by the photographs is the existence of crater-like punctures, some 0.06 mm in diameter, through the teflon layer from the front surface to the silver layer which coats the back surface of the sample. Puncture-type breakdowns occur in 1 mil teflon samples at an electron beam voltage of 10kV, whereas 3 mil teflon samples breakdown at a 24kV electron beam voltage. These values are to be compared with the 10-20kV negative potentials to which spacecraft surfaces become charged.

The charged particles emanating from the site of the puncture-type discharges have been measured with biased Faraday cups from which particle energies and charge-to-mass ratios may be inferred. Preliminary results indicate that both electrons and positive ions are emitted from the electrical discharge and that significant quantities of heated teflon are transported from the discharge site to the nearby dielectric surfaces. The extent to which these charged particles and other materials from the discharge site constitute sources of contaminants to spacecraft sensors and thermal control systems will be explored in the paper.

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OPTICAL PROPERTIES OF CRYOCONTAMINANTS

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ABSTRACT

The infrared spectral transmittance of cryodesposits formed by MMH, N_2O_4, and a simulated exhaust plume mixture (N_2 - 61%, CO_2 - 21%, CO - 10%, and H_2O - 8%) was measured. These deposits were cryopumped on a 20°K germanium substrate and ranged in thickness from 0.25 to 5 μm; the deposition pressure for the MMH and N_2O_4 deposits was 5×10^{-8} torr while that for the simulated plume mixture was about 1×10^{-6} torr. Transmission spectra were obtained for the 500 to 3700 wavenumber range using a Fourier transform spectrometer. In addition to the value of these spectra for contaminant identification, the integrated absorption serves as a quantitative measure of the contaminant in the case of pure cryodeposits.

The optical properties (n, k) of such cryodeposits are essential to predicting the degradation of plume contaminated cryocooled optical surfaces. Values of the complex index of refraction ($\hat{n}$ = n-ik) for the cryodeposits were derived from the experimental data using an analytical model and a non-linear least squares method. Our analytical model treats the germanium as a thick non-interfering film and the deposit as a thin film. Results from the least squares method are also compared with a Kramers-Kronig determination of the real part of the index of refraction.

Abstract

The experimental work of AESC on the Satellite Contamination Program is presented covering the two facilities used, special instrumentation and testing procedures developed, and a survey of the test results which demonstrate the general emission and adsorption characteristics of polymer outgassing in space and the effects of their condensible products on cold thermal control surfaces and optical train components.

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Under the recent AFML Satellite Contamination Program, AESC has been making experimental investigations on two important areas of the space contamination phenomenon. The areas covered by these studies involve the release of molecular volatile condensible materials (VCM) from non-metallic sources followed by the deposition of these VCM on colder receptor surfaces, and subsequently the effects on the thermal and optical properties of the contaminated receptors. Two very high vacuum ultra clean vacuum chambers are being used for this work. The Molecular Kinetics Testing Facility (Molekit) is utilized to measure the material properties which characterize the mass release, transport, and deposition of the VCM while the Surface Materials Effects Facility (SMEF) makes the subsequent effects measurements on typical contaminated receptor surfaces.

The principle device used in the Molekit is an array of quartz crystal microbalances (QCMs). In the SMEF, a dual beam integrating sphere is used to measure changes in the spectral reflectance and transmittance of contaminated receptor surfaces while the scatter effects are measured with an in-situ scatterometer. All data is acquired through automated programming and stored on magnetic tape with simultaneous real time plotting and printout. The kinetic properties and contamination effects under the influence of low level laser encounters and ultraviolet radiation are also being studied.

This report further details the calibration and testing procedures necessary to obtain the precise kinetics and transport data using typical QCMs over a wide temperature range from -170°C through 125°C and under very rapid changes in source heating. Special calibration procedures are required, particularly for the rapid source temperature rises associated with laser encounters. In the SMEF, special design and procedures are introduced to maintain the optical alignment of the integrating sphere optical train in the presence of large temperature gradients and to minimize in-situ background scattering of the laser beam used to make scattering measurements. Finally, the report presents a survey of the basic outgassing, transport, and deposition characteristics for the polymeric source materials examined and of the effects that their VCM has on several typical receptor surfaces.

CONTAMINATION EFFECTS AND OUTGAS SPECIES ANALYSIS OF SOME SPACECRAFT MATERIALS

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Measurements have been made to determine the relationship between the amount of outgas products from spacecraft materials condensed on spacecraft critical surfaces and the resulting change in their optical properties. The intent of the measurements was to generate engineering data to show trends rather than determine fundamental properties. The outgas sources used were S-13 GLO white paint; graphite-reinforced epoxy composite; Kapton tape; and FEP Teflon-silver second surface mirror tape, with SR-585 and P223 adhesives. The outgas source temperatures were 125°C and 176°C. The surface optical properties studied were the solar absorptance of aluminized Teflon flexible optical solar reflector (AL/FCSR) and the transmittance of solar cell cover glass. These surfaces were contaminated in vacuum at 25°C. The deposit densities studied ranged between 10^{-6} and 10^{-4} gms/cm^2. The basic experimental method was to arrange the test surface and a quartz crystal microbalance (QCM) in a vacuum chamber, so that both were at 25°C, and both had the same view factor to the orifice of a Knudsen cell-type outgas source material holder. It was then assumed that the contaminant mass per unit area collected on the QCM is the same as that on the collector surface.

Measurements have also been made to determine the number and volatility of the outgas species generated by the various source materials used in the contamination tests. The outgas products from source material samples were collected on a liquid nitrogen-cooled QCM. The QCM was then warmed up and the various species identified by fractional distillation. This process, which is referred to as QCM/Thermogravimetric analysis (QCM/TGA) is shown to be relatively successful, although careful technique is required. Problem areas where improvement in technique and/or data analysis are required are discussed.

THE INFLUENCE OF THE UV - INTENSITY ON I.F. FILTER PROTECTED SECOND SURFACE MIRROR ALPHA-S STABILITIES, INCLUDING SURFACES WITH CONDUCTIVE TOP LAYERS

by

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Recently SSM and OSR with improved alpha-s stability were reported.[1] To save time, the simulated UV - exposures were performed with 7.5 solar constants. However, it may be questionable, that this improved performance will show up under exposure with two or one solar constants. Therefore, current tests are directed toward study of the SSM alpha-s stability under exposure with smaller UV doses. Four identical sets of samples were exposed to UV, UV and 40 KeV protons, to 40 KeV protons, and to 40 KeV electrons. Each set contains eight samples.

Incorporated in these tests is .125 mm thick Teflon FEP, coated with seven layers of ZnS/Al_2O_3. Their back sides carry either an aluminum or a silver reflector, about 1500 Å thick.

Park of the tested and I.F. filter protected SSM are coated with a thin conductive top layer of In_2O_3, with 10% SnO_2. Study of the time stability of this top layer resistance is one feature of the current tests. On opposite sides two wires are glued on with Ecobond 57 C, permitting constant control of the resistance.

Ref. 1: O.K. Husmann and K. Kerner, "Solar Radiation Resistance Improvement of Second Surface Mirrors and Optical Solar Reflectors by Deposition of Interference Filters." J. Vac. Sci. Tech., Vol. 14, No. 1, p. 200, 1977, Jan/Feb.

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SILVER-TEFLON CONTAMINATION/ULTRAVIOLET RADIATION STUDIES

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The silver-Teflon radiator surfaces on the inside of the Shuttle Orbiter payload bay doors can potentially be degraded from Orbiter induced contaminants during normal operations. Evaluations have been performed to determine the in-situ change in solar absorptance of the silver-Teflon samples from .25 μm to 2.5 μm after UV irradiation of deposited film thicknesses (100 - 1000 Å) of Orbiter hydraulic fluid and RTV 560 outgassing products. Solar absorptance measurements were performed on the samples prior to deposition, after deposition and after UV irradiation. Irradiations were performed in the far UV, 122 and 147 nm, as well as from .25 μm to 2.5 μm for 48 and 300 hours. Cleaning techniques were investigated to study restoration of contaminated surfaces to their original values.